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Invention: SYSTEM AND METHOD OF MONITORING AUDIO SIGNALS

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SPECIFICATION

SYSTEM AND METHOD OF MONITORING AUDIO SIGNALS

Field Of The Invention

Aspects of the present invention relate generally to monitor and control systems, and more particularly to a system and method of acquiring, recording, and implementing audio signal data.

Description Of The Related Art

Conventional data monitoring and process control systems rely upon dedicated wire-lines to enable communication and data transfer between a control system and a remote sensor or actuator device. Dedicated wire-lines typically limit the utility of a remote device or an associated monitor and control system in at least the following respects: acceptable locations for the remote device are generally restricted by the requirement that the remote device have convenient access to the wire-line; and the remote device may respond only to a single control system or apparatus (*i.e.* that which is connected to the wire-line).

Recent developments in Internet Protocol (IP) communications and in local area networking technology have enabled monitoring and control of various devices and industrial processes from multiple remote locations simultaneously. While myriad data signals and process parameters may be monitored, those of skill in the art recognize that the particular data signals selected for monitoring may have a significant impact on the utility of the monitor and control system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified block diagram illustrating one embodiment of a data logging system which may employ an audio signal acquisition module.

FIG. 2 is a simplified block diagram illustrating one embodiment of a data logging apparatus configured to record audio signals and other data.

FIG. 3 is a simplified flow diagram illustrating the general operational flow of one embodiment of an audio signal data acquisition method.

FIG. 4 is a simplified block diagram illustrating one embodiment of an audio signal input/output apparatus.

FIG. 5 is a simplified flow diagram illustrating the general operational flow of one embodiment of a monitor and control system responsive to audio signal data.

DETAILED DESCRIPTION

Embodiments of the present invention overcome various shortcomings of conventional technology, providing a system and method of audio signal data acquisition and implementation in a data logging system.

In accordance with one aspect of the present invention, a system and method of logging audio signal data implement a data buffer and a non-volatile data storage medium. Acquired data may be stored in the buffer temporarily, for example, until a threshold amount or volume of data has accumulated in the buffer. Buffered audio and other data may be written to the non-volatile storage medium in large blocks, minimizing the number of write operations to the non-volatile storage medium.

Audio signal data stored in such a non-volatile storage medium may subsequently be processed and analyzed by an administrator, for example, or by system diagnostics software. Additionally or alternatively, monitored audio signal data may be employed for real-time process or system control. It will be appreciated that the disclosed system and method are readily provided with appropriate hardware and transducers to monitor subsonic, supersonic, and ultrasonic signals as well as audible signals within a predetermined or dynamic frequency range; any or all acquired audible, subsonic, or supersonic signals may be employed to facilitate device or system control.

In that regard, the terms "audio signals," "audio data," and variants thereof as used herein refer not only to signals (or data representative of such signals) which are perceptible within the normal range of human hearing, but also to signals well beyond the limited frequency range of human sensitivity; *i.e.* "audio" in this context is not equivalent to "audible." For simplicity and clarity, continued references to subsonic, supersonic, or ultrasonic signals have been omitted from portions of the present disclosure, however, those of skill in the art will appreciate that references to "audio" signals are intended to encompass signals extending into subsonic, supersonic, and ultrasonic regions of the sonic frequency spectrum.

The foregoing and other aspects of various embodiments of the present invention will be apparent through examination of the following detailed description thereof in conjunction with the accompanying drawings.

Turning now to the drawings, FIG. 1 is a simplified block diagram illustrating one embodiment of a data logging system which may employ an audio signal acquisition module. In the exemplary embodiment, system 100 generally comprises a housing or rack 110 accommodating and interconnecting removable modules 120-160. When constructed and operative in accordance with the FIG. 1 embodiment, system 100 may function as an input/output monitoring and data logging device, and additionally may provide control signals as set forth in detail below.

As illustrated in FIG. 1, removable modules may include one or more of the following: a control (brain) module 120; one or more data acquisition and transmission (sensor) modules 131-133; a data logging module 140; and an audio sensor module 160. For clarity, only four sensor modules (131-133 and 160) and one data logging module 140 are depicted in FIG. 1. Those of skill in the art will appreciate that the FIG. 1 embodiment is presented for illustrative purposes only, and that system 100 may be implemented with any number of sensor modules and one or more additional data logging modules.

System 100 may be constructed and arranged such that insertion of a removable module 120-160 into housing or rack 110 automatically creates necessary electrical and data communication connections via a bus 199, for example, or other communication pathway. Such "plug-and-play" versatility may enable system 100 to perform different functions depending upon the number, type, and particular configuration of removable modules 120-160 coupled to rack 110. As set forth in more detail below, data communication between removable modules 120-160 may be in accordance with any protocol known in the art or developed and operative in accordance with known principles.

By way of example, sensor modules 131-133 and 160 may include suitable hardware, firmware, software, or a combination thereof operative to transmit and to

receive data. As illustrated in FIG. 1, sensor modules 131-133 and 160 may generally be configured to monitor the operation of, and to receive data output from, respective sensors 191-194. Sensors 191-193 represent any number of devices including, but not limited to, the following: thermistors, thermocouples, or other temperature measuring equipment; tachometers; speedometers; pressure gauges; fluid flow meters; gyroscopes; infrared or motion detectors; or any other similar meters, gauges, or indicators capable of generating output which may be monitored by sensor modules 131-133.

In particular, audio sensor 194 may be an acoustic or other audio signal sensor coupled to audio sensor module 160. Audio signals may be particularly useful in analyzing process progression and system performance. Audio signal frequency and amplitude, for example, may provide critical real-time or near real-time information related to functional aspects or operational characteristics of one or more system components. As set forth above, audio sensor 194 may comprise one or more transducers operative to detect subsonic or supersonic signals beyond the audible range of frequencies; such subsonic or supersonic audio signals may facilitate control operations in a similar manner as audible signals.

Additionally or alternatively, one or more sensor modules may be configured to transmit control signals or other desired data to remote equipment such as, for example: control modules implemented in computer hardware or software; computer-based or electronically controlled machinery; actuators; servos; hydraulic systems; electronic circuits; and any other devices to be controlled by system 100.

Brain module 120 may be any machine intelligence capable of two-way data communication with sensor modules 131-133,160 and data logging module 140. In the FIG. 1 embodiment, brain module 120 may additionally be capable of interfacing data received from other components of system 100 with remote equipment such as a computer or wireless device (not shown) over a network. In operation, brain module 120 may execute computer programs or instructions encoded on computer-readable media, for example, to configure sensor modules 131-133,160 and data logging module 140. Brain module 120 may also execute computer instructions to perform

control functions or otherwise to manipulate actuators or other remote devices coupled to modules 131-133 as discussed above.

In that regard, brain module 120 may incorporate a microprocessor or microcontroller based microcomputer and include sufficient communications interfaces (logical and physical layers) to enable the data communication illustrated graphically in FIG. 1. One or more communications interfaces may generally be dedicated to communicating with modules 131-160, and one or more communications interfaces may generally be dedicated to communicating to other networked devices, such as equipment connected to a Local Area Network (LAN), a Wide Area Network (WAN), a Virtual Private Network (VPN), and the like. In some embodiments, brain module 120 may be implemented as a programmable logic controller (PLC).

Data logging module 140 may generally be operative to receive and to store data monitored and acquired by sensor modules 131-133,160. In that regard, data logging module 140 may be operatively coupled with brain module 120 via appropriate hardware and software supporting a two-way data communication link; data logging module 140 may additionally be operatively coupled with one or more sensor modules 131-133,160 via a similar two-way data connection. The hardware and software components necessary to enable such communication are omitted from FIG. 1 for clarity.

In operation, data logging module 140 may receive configuration instructions from brain module 120 specifying monitor and control parameters for data logging procedures. Through such configuration, data logging module 140 may be instructed regarding which types of data are to be recorded at specified time intervals, for example, or at which data measurement levels an alarm is to be issued. Data logging module 140 may then manage data acquisition and recordation functions in accordance with such configuration instructions. It will be appreciated that data logging module 140 may acquire data either from brain module 120, from sensor modules 131-133,160 directly, or from a combination thereof, depending upon, for

example, the specific configuration instructions received from brain module 120 and the interface between modules 120-160.

In one embodiment mentioned above, an interface between brain module 120 and the other removable modules 131-160 may be integrated, or hard-wired, into housing or rack 110 such that electrical connections and data interfaces (represented in FIG. 1 by bus 199) required for operation of, and bi-directional communication between, modules 120-160 may be made automatically upon insertion into rack 110. By way of example, the data connection may be a serial or parallel link. Alternatively, the data connection may be any type generally known in the art for communicating or transmitting data across a computer network; examples of such networking connections and protocols include, but are not limited to, Transmission Control Protocol/Internet Protocol (TCP/IP), Ethernet, Fiber Distributed Data Interface (FDDI), ARCNET, token bus or token ring networks, Universal Serial Bus (USB), and Institute of Electrical & Electronics Engineers (IEEE) 1394 (typically referred to as "FireWire"). Other types of data network interfaces and protocols, such as wireless infrared (IR) and radio frequency (RF) communications standards, are within the scope and contemplation of the present disclosure.

FIG. 2 is a simplified block diagram illustrating one embodiment of a data logging apparatus. Data logging module 240 corresponds generally to data logging module 140 described above with reference to FIG. 1. Data logging module 240 may include data logging logic 241, a data buffer 242, a real time-clock 243, and a non-volatile data storage medium 244. As noted above with reference to FIG. 1, a data logging module 240 may include hardware and software supporting a two-way data communication link with a brain module.

Data logging logic 241 may manage all data acquisition and recordation functions in accordance with configuration instructions, for example, which may be received from a brain module. A two-way data communication link between logic 241 and a brain module is represented by a data bus 289 in FIG. 2. As discussed briefly above, logic 241 may additionally or alternatively include necessary hardware and software to support similar data communication links to one or more sensor

modules 231-233,260. The data links may be implemented along the same data bus 289 coupling logic 241 and the brain module, or alternatively may employ one or more dedicated buses 283,284.

Depending upon the specific system configuration and modular hardware arrangement, data acquisition may be through one or more sensor modules 233,260 directly, via respective dedicated buses 283,284, for example, or through the brain module via bus 289. Buses 283, 284, and 289 may operate in accordance with any of the network interface protocols noted above, or with other data interface technologies known in the art or operative in accordance with known principles.

Brain module may configure logic 241 to acquire specified data measurements at specified time intervals, for example, or to record the time at which a data measurement at a specified sensor module 231-233,260 deviates from a certain value range. It will be appreciated that the particular configuration and responsibilities of logic 241 may vary considerably, depending upon the overall arrangement and desired functionality of the system in which data logging module 240 is employed.

In a reconfigurable embodiment such as illustrated in FIG. 2, the functionality of logic 241 may be implemented in software code or programmable firmware instructions, for example, such that new configuration instructions may be accepted from the brain module via bus 289. New configuration instructions may be operative to modify the functionality of logic 241. In an alternative embodiment, some or all of the functional capabilities of logic 241 may be exclusively or primarily hardware-based, such as may be enabled through use of an integrated circuit board or programmed logic board. In this embodiment, data logging module 240 may employ predominantly dedicated data communication links such as data buses 283,284 to maintain a direct link between logic 241 and the various sensor modules 231-233,260.

Logic 241 may be constructed and implemented to be removable from data logging module 240. The general operation of data logging module 240 may be altered or improved, for example, through removal and replacement of logic 241. By

way of example, logic 241 may be replaced by a different logic board or a newer version of software program code having different capabilities; accordingly, operation of data logging module 240 may be modified or improved without replacement of the entire module 240 hardware. In this embodiment, logic 241 may reside on a PLC or other dedicated integrated circuit board or chip.

The hardware arrangement of FIG. 2 accommodates one embodiment in which the brain module monitors and collects data acquired by sensor modules 231-233,260. Data logging logic 241 may be configured to query the brain module at specified intervals, for example, and to request transmission of collected data via bus 289. Alternatively, logic 241 may be configured to remain passive; the brain module may be responsible for transmitting collected data independent of any query or request from logic 241.

All monitored and collected data may be directed from logic 241 to data buffer 242. As an alternative, logic 241 may be configured to transmit only selected or particular data points to data buffer 242. It will be appreciated by those of skill in the art that data may be moved to buffer 242 in an unaltered state, *i.e.* in "raw" form. Additionally or alternatively, logic 241 may be configured to process some or all of the raw data, such as through normalization algorithms or regression procedures, for example, prior to transmission to buffer 242.

Data buffer 242 may be implemented as random access memory (RAM) having an associated battery or other independent ("backup") power supply (not shown); an independent backup power supply may prevent data stored in buffer 242 from being irretrievably lost in the event of temporary power loss to data logging module 240. Data buffer 242 may selectively include sufficient storage capacity to accommodate a desired amount of data; accordingly, the capacity of buffer 242 may depend, in part, upon the desired operational characteristics of the system as a whole.

For example, where few sensor modules are employed to make infrequent measurements or otherwise to acquire relatively little data, data buffer 242 may have a 16 kilobyte (k) or 32k capacity as illustrated in FIG. 2. Conversely, where many sensors are employed to acquire relatively voluminous data records, data buffer 242

may have a 128 Megabyte (Mb) or 256Mb capacity. The size and format of each data record may affect the desired capacity of buffer 242.

Data logging module 240 may include one or more input/output ports or expansion slots which may accommodate, for example, removable RAM chips such as Single In-line Memory Modules (SIMMs), Dual In-line Memory Modules (DIMMs), or the like. Such an embodiment allows various combinations of data storage components to be inserted or removed such that the capacity of data buffer 242 may be selectively altered.

Buffer monitor circuitry or software code resident, for example, in buffer 242 itself or in logic 241, may monitor the amount or volume of data sent to data buffer 242. When such a buffer monitor (not shown) determines that the amount of data stored in data buffer 242 has reached or exceeded a predetermined threshold, the data records contained in buffer 242 may be transferred to non-volatile data storage medium 244. The predetermined threshold may be a specified volume of data measured, for example, in bytes; similarly, the threshold may be calculated as a predetermined percentage of the total capacity of data buffer 242.

Non-volatile data storage medium 244 may be a magnetic or optical disk, a compact disk, bubble memory, flash memory, and the like as known in the art, or any other non-volatile data storage medium to which data records may be written. The present disclosure is not intended to be limited by the form or constitution of non-volatile data storage medium 244.

In one embodiment, non-volatile storage medium 244 may be removable from data logging module 240, such that storage medium 244 may be inserted into another device for data retrieval, analysis, transfer, or transmission. For example, a storage medium 244 implemented as a flash memory card or multimedia card (MMC) may be removed from data logging module 240 and inserted into a data reading device, a desktop or portable computer, a workstation, or the like, for data retrieval or analysis.

Additionally or alternatively, data may be transmitted from data logging module 240 to a remote device. Data transmission may be enabled through an output

port at the brain module, for example, which may be connected to a network as described above with reference to FIG. 1; in another embodiment, data may be transmitted through an output port (not shown) integrated with module 240.

Those of skill in the art will appreciate that the format in which data records are written to storage medium 244 may influence the manner in which those data records may be transmitted, and vice-versa. In some embodiments, data may be stored in File Allocation Table (FAT) format, for example, and may be transmitted in accordance with File Transfer Protocol (FTP) or other data transmission protocols. Data records in FAT format are generally readable by common personal computer and workstation operating systems, for example.

Additionally or alternatively, data may be stored in various other formats including, but not limited to, Journaling Flash File System, compact flash file system formats (*e.g.* FlashFX), High Performance File System (HPFS), and the like. The present disclosure is not intended to be limited by the data transmission protocol employed to transmit data from module 240; in addition to FTP mentioned above, other protocols may selectively be employed as a function of the overall system environment, for instance, and other factors. For example, data may be transmitted from module 240 in accordance with Network File System (NFS) protocol, Hyper-Text Transfer Protocol (HTTP), various derivatives thereof such as HTTP Secure (HTTPS) which employs Secure Sockets Layer (SSL) technology, and other protocols known in the art or developed according to known principles.

Data may be moved from buffer 242 to non-volatile medium 244 in large blocks. In one embodiment, the entire contents of buffer 242 may be written to non-volatile medium 244 in a single write operation. The foregoing storage strategies in conjunction with buffer 242 may minimize the number of write cycles experienced by non-volatile medium 244. Temporary storage of monitored data in buffer 242 may substantially increase the useful life of non-volatile medium 244 implemented in a flash memory card, which may only be operative for a limited number of write cycles, for example.

Data logging module 240 may employ real-time clock 243, for example, to time-stamp data measurements or data write cycles. Accordingly, each data record written to non-volatile medium 244 may be provided with an associated time-stamp which may be retrieved with the data record. By way of example, a time-stamp associated with data records may enable a system administrator to evaluate the manner in which system performance varies over time or to estimate when testing or maintenance should be performed.

Though it is also possible to time-stamp acquired data after buffering, *i.e.* as the data are written to non-volatile medium 244, the FIG. 2 embodiment illustrates data records receiving a time-stamp before the acquired data are sent to buffer 242, *i.e.* as the data are acquired by module 240. In some applications, the accuracy of the data record time-stamps may be critical to system diagnostic analyses or performance evaluations; additionally, the transfer of data from buffer 242 to non-volatile storage medium 244 may occur well after the data are acquired, depending upon the rate of data acquisition and the capacity of buffer 242, for example. In that regard, the FIG. 2 arrangement may be appropriate for many applications requiring accurate time-stamp information associated with every data record.

FIG. 3 is a simplified flow diagram illustrating the general operational flow of one embodiment of an audio signal data acquisition method. The method depicted in FIG. 3 may be enabled by a system employing an audio sensor module and a data logging module such as described in detail with reference to FIGS. 1 and 2.

As indicated at block 301, data logging logic may be configured with instructions related to operational parameters of data monitoring and recordation functions. Logic implemented in hardware which is not programmable may be hardwired (*i.e.* "preconfigured" during fabrication, for example) to operate in a particular fashion, whereas programmable (*i.e.* reconfigurable) firmware or software logic may receive configuration instructions from an external source such as a brain module as discussed above with reference to FIGS. 1 and 2.

Depending upon the configuration, data logging logic may query one or more system components (such as an audio sensor module) for data records; such a request

for data, indicated at block 302, may generally employ any of the system components and architecture described above with reference to FIG. 2. In an alternative embodiment, an audio sensor module may be configured to transmit some or all acquired audio data measurements (*e.g.* related to audible, subsonic, supersonic, or all signals) to data logging logic automatically, *i.e.* independent of a query or request.

Audio data to be logged may be received by data logging logic as indicated at block 303. As described above, data logging logic may store received audio data in a data buffer (block 304). In some embodiments, instruction code resident in data logging logic may selectively execute one or more data processing or time-stamping operations before directing the received audio data to storage in the buffer; additionally or alternatively, any computational results derived from received audio data may also be stored in the buffer. For example, frequency or wavelength normalization, regression, statistical analysis, and the like, as well as comparisons with signature audio signals and any other appropriate data processing techniques, may be performed by data logging logic prior to directing data to the data buffer at block 304. Alternatively, some or all audio data may be stored directly into the data buffer without any processing by data logging logic, *i.e.* in raw form.

Data buffers generally have a limited capacity; a method of logging audio data may employ buffer monitor circuitry or software code as described above, for example, to monitor the amount or volume of data sent to the buffer. When such a buffer monitor determines that the content of the data buffer has reached or exceeded a predetermined threshold (a predetermined value or a predetermined percentage of total capacity, for example), audio data records and associated time-stamp information stored temporarily in the buffer may be written to a non-volatile data storage medium as described above with reference to FIG. 2.

The decision block 305 in FIG. 3 represents the above-described determination. As indicated at block 306, if the buffer contents have reached or exceed the predetermined threshold, audio and other data in the buffer may be moved to non-volatile storage. During data logging procedures, while the data

content of the buffer has not reached the predetermined threshold, however, the data logging module may continue to receive additional data for storage in the buffer, as indicated by the loop back to block 303.

FIG. 4 is a simplified high-level block diagram illustrating one embodiment of an audio signal input/output apparatus. Audio sensor module 460 corresponds generally to audio sensor module 160 described above with reference to FIG. 1, and may generally be operative to receive data signals from an audio sensor 494, which may be operative to provide audible, subsonic, or supersonic signal data. Audio sensor module 460 may include audio diagnostic logic 462, an audio data storage medium 464, and an analog to digital (A/D) converter 466.

As illustrated and described above with reference to FIG. 1, module 460 may be coupled with a brain module via a two-way data communication link as represented by bus 489; additionally or alternatively, module 460 may be coupled with a data logging module via a similar two-way data communication link as represented by bus 484. It will be appreciated that the foregoing bi-directional data communication may be enabled by one or more appropriate network or communication interfaces (not shown); accordingly, module 460 may include suitable hardware, software code, and interfacing structure to enable coupling to a network or to other modules as described above. Such hardware components and software blocks are omitted from FIG. 4 for clarity.

Audio diagnostic logic 462 may manage all data acquisition functions in accordance with configuration instructions, for example, which may be received from a brain module. For instance, logic 462 may be configured to acquire specified data measurements at specified time intervals, to record the time at which an audio signal frequency deviates from a predetermined or selected range, or to compare an acquired audio signal with a signature audio signal data record maintained in storage medium 464.

It will be appreciated that the particular configuration and responsibilities of logic 462 may vary considerably, depending upon the overall arrangement and desired functionality of the system in which module 460 is employed. In some

embodiments, logic 462 may be configured to transmit audio signal data to a brain module upon acquisition; accordingly, the brain module may implement audio signal data in real-time or near-real-time system diagnostics or control applications.

In a reconfigurable embodiment such as illustrated in FIG. 4, the functionality of logic 462 may be implemented in software code or programmable firmware instructions, for example, such that new configuration instructions may be accepted from the brain module via bus 489. New configuration instructions may be operative to modify the functionality or the operational parameters of logic 462. In an alternative embodiment, some or all of the functional capabilities of logic 462 may be exclusively or primarily hardware-based, such as may be enabled through use of an integrated circuit board or programmed logic board.

As with the data logging logic 241 described above with reference to FIG. 2, audio diagnostic logic 462 may be constructed and implemented to be removable from module 460. The general operation of module 460 may be altered or improved, for example, through removal and replacement of logic 462.

Audio data storage medium 464 may be operative to store acquired audio data, information related to the acquired audio data, and other selected data, instructions, information, and so forth. Audio data storage medium 464 may be embodied in similar hardware as non-volatile storage medium 244 in FIG. 2, *i.e.* a magnetic, optical, or compact disk, bubble memory, flash memory, and the like. Storage medium 464 may also be removable; upon removal from module 460, storage medium 464 may be inserted into another device for data retrieval, analysis, transfer, or transmission.

Storage medium 464 may include data records of signature audio signals, for example, or configuration instructions. In an alternative embodiment, storage medium 464 may additionally maintain data records related to acquired audio signals; in that regard, audio sensor module 460 may incorporate some of the functionality of data logging module 240 illustrated and described above with reference to FIG. 2.

In operation of module 460, A/D converter 466 may convert analog audio signals transmitted from sensor 494 into digital signals for logic 462. While illustrated as an independent component of module 460, the circuitry required to support the functionality of A/D converter 466 may be integrated with the audio sensor 494 itself, for example, or with logic 462. In cases where audio sensor 494 generates digital signals, A/D converter 466 may be bypassed as indicated in FIG. 4.

It will be appreciated that audio sensor module 460 may compare an acquired sound or audio signal (obtained from a microphone, an acoustic sensor, a subsonic or supersonic transducer, or other sensors, for example) to one or more reference sounds or signature audio signal profiles stored in storage medium 464. In some embodiments, audio diagnostic logic 462 may make a binary or "pass/fail" determination with respect to the comparison of acquired audio signals relative to signature audio signal profiles. The comparison of acquired audio signals, which may include frequency and wavelength analysis, with stored reference data or signature audio signal profiles may enable a monitor and control system, such as system 100 in FIG. 1, to function as an input/output monitoring and control apparatus responsive to audio or acoustic signal information.

FIG. 5 is a simplified flow diagram illustrating the general operational flow of one embodiment of a monitor and control system responsive to audio signal data. In the FIG. 5 embodiment, a signature audio signal profile (*i.e.* a reference or sample audio signal) is obtained as indicated at block 501. By way of example, the sound of a pump, motor, or other apparatus operating normally may have a recognizable spectral profile, for instance, comprising distinct frequency and wavelength characteristics. Similarly, the sound generated during irregular or distressed operation may be characteristic of a particular mode of failure or symptomatic of an impending failure. Those of skill in the art will appreciate that many types of signature audio signal profiles may be obtained for system analysis and diagnostic or control applications.

Audio profile data representative of the sound or subsonic or supersonic signals generated during operation of a particular machine, apparatus, or component

thereof may be acquired (block 501) and stored in a data storage medium (block 502); as illustrated and described above in detail with reference to FIG. 4, an audio data storage medium may be incorporated in an audio sensor module or audio data input/output apparatus. Various audio profiles, representative of normal operation as well as one or more potential failure modes, for example, may be stored at block 502.

During operation of a particular system component, the sound or audio spectral content generated during operation of a given system component may be monitored and acquired as indicated at block 503. As set forth above, audio signal data acquired at block 503 (which may be obtained from a microphone or other sensor) may be compared to one or more of the audio profiles or sample spectra stored in the audio data storage medium. One or more signature audio signal profiles may be retrieved from the storage medium, for example, and analyzed relative to the acquired audio signals as set forth below; this comparison is represented by block 504 in the FIG. 5 embodiment.

Upon retrieval of selected or predetermined signature audio signal profiles from the storage medium, the comparison at block 504 may be executed by logic hardware or software, for example, resident at an audio sensor module such as illustrated and described in detail above with reference to FIG. 4. The comparison of acquired audio data with one or more signature audio profiles may comprise a convolution algorithm in either the time domain or the frequency domain, for example, or other data processing operations. Referring to the exemplary hardware arrangements of FIGS. 1 and 4, an audio sensor module may provide a control or brain module with data or other information indicative of the comparison result of block 504; additionally or alternatively, an audio sensor module may transmit raw data to a brain module or other control hardware responsible for executing the foregoing comparison independent of any processing at the audio sensor module.

As represented at decision block 505, a determination may be made with respect to the how closely the acquired audio signals approximate the reference or signature audio signals. A brain module, for example, or other hardware or control

logic may perform functions or execute instructions based upon the determination at decision block 505. For each acquired signal, an assigned value or parameter may be representative of the degree of similarity with one or more audio profiles maintained in a storage medium as set forth in detail above. A high degree of similarity between the acquired audio signals and a signature audio signal profile characteristic of normal operation may indicate that no control action is required. Conversely, a high degree of similarity between the acquired audio signal and a signature audio signal profile which represents a failure or other irregular operation may indicate that some control action is warranted.

As indicated in FIG. 5, a determination at decision block 505 may result in execution of some control function as represented at block 506. For example, motors or other equipment which are determined to be operating in an undesirable manner may be tuned, lubricated, adjusted, disengaged, deactivated, or otherwise shut-down. As another example, audio signals indicative of equipment which is functioning outside of normally acceptable operational thresholds may trigger alarms, initiate system or component shut-down, activate systems or components to correct malfunctions, and so forth. Those of skill in the art will appreciate that the nature and complexity of the control operation represented at block 506 may vary considerably as a function of overall system configuration and requirements.

Acquired audio signals which fall within an acceptable range relative to stored audio data may indicate that no control procedures are required, in which case the FIG. 5 embodiment may continue monitoring audio signal data as illustrated by the loop back to block 503.

Several features and aspects of the present invention have been illustrated and described in detail with reference to particular embodiments by way of example only, and not by way of limitation. Those of skill in the art will appreciate that alternative implementations and various modifications to the disclosed embodiments are within the scope and contemplation of the invention. Therefore, it is intended that the invention be considered as limited only by the scope of the appended claims.